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METHOD AND INSTALLATION FOR THE PRODUCTION OF HOT-ROLLED STRIP WITH A DUAL-PHASE MICROSTRUCTURE

The invention concerns a method for producing hot-rolled strip with a dual-phase microstructure consisting of ferrite and martensite, wherein at least 70% of the austenite is transformed to ferrite from the hot-rolled state by a controlled two-stage cooling operation after the finish rolling to a strip temperature below the martensite start temperature in a cooling line that consists of successive, spaced water cooling units.

Systematic microstructural transformation by controlled cooling is steels is well known, and to produce dual-phase steels, this controlled cooling is carried out after the working of the hot strip is complete. The adjustment of the attainable dual-phase microstructure depends essentially on the cooling rates that are technically possible in the installation and on the chemical composition of the steel. In this regard, it is important in any case to achieve sufficient ferrite formation of at least 70% in the first cooling stage. During this first

cooling stage, transformation of the austenite in the pearlite stage should be avoided.

The cooling capacity of the second cooling stage following the first cooling stage must be sufficiently high that coiling temperatures below the martensite start temperature are reached. Only then is the formation of a dual-phase microstructure with ferritic and martensitic constituents ensured.

The previously known production of dual-phase steels is unproblematic at low strip speeds or with sufficiently long cooling lines. However, at very high strip speeds, the beginning of the second cooling stage can be shifted so far in the present cooling line that the subsequent martensite formation remains incomplete or does not occur at all. This results in a mixed microstructure consisting of ferrite, bainite and some martensite, so that the desired mechanical properties of a pure dual-phase microstructure are not obtained.

EP 0 747 495 B1 describes a method for producing high-strength steel plate with a microstructure consisting of 75% ferrite, at least 10% martensite and possibly bainite and retained austenite. Accordingly, this is not a microstructure of pure dual-phase steels. A steel microalloyed with niobium is used as the alloy. It is produced by systematically cooling the

hot-rolled steel plate, wherein a rapid cooling follows a slow cooling or, alternatively, a rapid cooling precedes the slow cooling. A cooling rate of 2-15°C/s within a cooling time of 8-40 s is given for the first cooling stage to a final temperature between the AR_1 point and 730°C. In the second cooling stage, the steel is cooled to a temperature of 300°C at a cooling rate of 20-150°C/s. In the alternative method, in which the rapid cooling stage precedes the slow cooling stage, rapid cooling is carried out to a temperature below the Ar_3 point at a cooling rate of 20-150°C/s.

EP 1 108 072 B1 describes a method for producing dual-phase steels, in which a dual-phase microstructure consisting of 70-90% ferrite and 30-10% martensite is achieved with a two-stage cooling operation (first slow, then rapid) carried out after the finish rolling. The first (slow) cooling is carried out in a cooling line in which the hot-rolled strip is cooled in a well-defined way by successive, spaced water cooling zones at a cooling rate of 20-30 K/s. In this connection, the cooling is adjusted in such a way that the cooling curve enters the ferrite range at a temperature that is still so high that ferrite formation can occur rapidly. The first cooling is continued until at least 70% of the austenite has transformed to ferrite.

This cooling stage is immediately followed by the other (rapid) cooling stage without any holding time.

Proceeding from the aforementioned prior art with the various possible means that have been described for producing dual-phase microstructure, the objective of the invention is to specify a method by which and an installation in which the production of hot-rolled strip with dual-phase microstructure can be carried out in a conventional continuous casting and rolling installation with the local limitations that exist there and thus with the given time constraints. The cooling line of an installation of this type is characterized by the fact that the total length generally does not exceed 50 m and that compact cooling is not provided.

The objective with respect to the method is achieved with the characterizing features of Claim 1. The method is characterized by the fact that, to obtain a hot-rolled strip with a dual-phase microstructure consisting of 70-95% ferrite and 30-5% martensite with high mechanical strength and high formability (tensile strength greater than 600 MPa, elongation after fracture at least 25%) in the cooling line of a continuous casting and rolling installation, starting from a steel with the following chemical composition: 0.01-0.08% C, 0.9% Si, 0.5-1.6%

Mn, 1.2% Al, 0.3-1.2% Cr, with the remainder consisting of Fe and customary trace elements, the two-stage controlled cooling is carried out from a finish rolling strip temperature T_{finish}, such that A_3 = 100 K < T_{finish} < A_3 = 50 K, to a coiling strip temperature $T_{coiling}$ < 300°C (< martensite start temperature), wherein the cooling rate $V_{1,2}$ in both cooling stages is V = 30-150 K/s, and preferably V = 50-90 K/s, the first cooling stage is carried out until the cooling curve enters the ferrite range, and then the heat of transformation liberated by the transformation of the austenite to ferrite is used for isothermally holding the strip temperature thereby reached for a holding time of 5 s until the beginning of the second cooling stage.

Due to the short length of conventional cooling lines in existing continuous casting and rolling installation, the production of hot-rolled strip with a dual-phase microstructure is possible only with a special cooling strategy. To allow a special cooling strategy of this type to be carried out, it is absolutely necessary to maintain certain limits of chemical composition, such as those listed in Claim 1, so that the desired degree of transformation can be achieved with the short total cooling time that is available.

The cooling strategy involves two cooling stages that have selectively variable cooling rates and are interrupted by an isothermal holding time of a maximum of 5 s. The beginning of the holding time, which corresponds to the end of the first cooling stage, is determined by the entrance of the cooling curve into the ferrite range, i.e., the point at which the austenite starts to transform to ferrite. The entire desired transformation of the austenite to at least 70% ferrite occurs in the short isothermal cooling interruption of a maximum of 5 s, during which, in accordance with the invention, the liberated heat of transformation holds the temperature at a constant value by compensating unavoidable air cooling. This holding time is then immediately followed by the second cooling stage, during which the hot-rolled strip is cooled to a temperature below 300°C. Since this temperature is below the martensite start temperature, the desired level of martensite, which is the second constituent of the dual-phase microstructure, is thus obtained.

In addition to the use of a short holding time, the cooling strategy is defined by an exactly defined, predetermined cooling rate for both cooling stages. This cooling rate is V = 30-150 K/s, and preferably V = 50-90 K/s. It depends on the geometry

of the hot-rolled strip and on the chemical composition of the grade of steel that is used. In regard to these cooling rates, it should be noted that a cooling rate of less than 30 K/s is not possible due to the small amount of time available in the conventional cooling line of a continuous casting and rolling installation, and cooling rates greater than 150 K/s also cannot be attained in conventional cooling lines.

Compared to prior-art methods for producing dual-phase hot-rolled strip, the method of the invention is characterized not only by the fact that the initial steel has a different chemical composition but also by the fact that

(a) the finish rolling temperature is well below the A_3 temperature,

(b) cooling is carried out to a temperature below 300°C in the second cooling stage,

(c) the cooling rates are below 150 K/s and above 30 K/s,

(d) there is a very short holding time of a maximum of 5 seconds, during which no cooling occurs, between the two cooling stages, and

(e) the transformation to ferrite occurs isothermally.

A continuous casting and rolling installation for carrying out the method of the invention is characterized by a

conventional cooling line that is installed after the last finishing stand and has several successive, spaced water cooling units, which can be automatically controlled. The spray bars present in each cooling unit are arranged in such a way that a specific amount of water is uniformly sprayed onto the upper and lower surfaces of the hot-rolled strip. The total amount of water can be automatically controlled by turning individual spray bars on or off during rolling. The number and arrangement of the water spray bars that are turned on can be variably adjusted in advance to obtain an optimum adjustment of the entire cooling line to the cooling conditions that are to be established.

Further details, features and characteristic of the invention are explained in greater detail below with reference to the specific embodiment of the invention that is illustrated in the schematic drawings.

-- Figure 1 shows a time-temperature cooling curve of a hot-rolled strip.

-- Figure 2 shows a layout of a cooling line in a continuous casting and rolling installation with a 6-stand finishing train.

-- Figure 3 shows a layout of a cooling line in a

continuous casting and rolling installation with a 7-stand finishing train.

-- Figure 1 shows an example of a time-temperature cooling curve of a hot-rolled strip that was cooled by the method of the invention on the runout roller table in a cooling line 1. The hot-rolled strip, which had the following composition: 0.06% C, 0.1% Si, 1.2% Mn, 0.015% P, 0.06% S, 0.036% Al, 0.15% Cu, 0.054% Ni, 0.71% Cr, the remainder consisting of Fe and customary trace elements, was cooled in a first cooling stage at a cooling rate V_1 of 54 K/s from an adjusted finish rolling temperature T_{finish} of 800°C to a hot-rolled strip temperature of 670°C, at which the cooling curve entered the ferrite range. During a holding time of about 4 s, the temperature of the hot-rolled strip remained at this holding temperature $T_{const.}$, and then the final cooling was carried out in a second cooling stage, in which the strip was cooled to a temperature below 300°C (about 250°C coiling temperature) at a cooling rate V_2 of 84 K/s. Tests on the hot-rolled strip produced by this method, which had a dual-phase microstructure in the desired range of at least 70% ferrite and less than 20% martensite, yielded a tensile strength of 620 MPa combined with a ratio of yield stress to tensile strength of 0.52.

Figure 2 shows an example of a layout of a cooling line 1 of a conventional continuous casting and rolling installation. The cooling line 1, through which the hot-rolled strip passes in direction of conveyance 8, is located between the last finishing stand 2 and the coiler 5. A temperature-measuring point 6 for monitoring the temperature of the hot-rolled strip 10 entering the cooling line 1 is located between the last finishing stand 2 and the first water cooling unit 3_1. The cooling line 1 shown in Figure 2 comprises a total of eight cooling units 3_{1-7} and 4. The latter is often realized as a trimming zone 4. More generally, a conventional cooling line comprises six to nine cooling units, depending on the particular continuous casting and rolling installation.

The example illustrated in Figure 2 is the typical layout of a cooling line for a 6-stand continuous casting and rolling installation, as is apparent from the gap between cooling units 3_7 and 4. Subsequent conversion to a 7-stand finishing train often requires that, for example, the first cooling unit (cooling zone) 3_1 be moved to the rear into the structural gap between the cooling units 3_7 and 4. In this case, the cooling line 1' has a layout of the type shown in Figure 3, which differs from the layout of the cooling line 1 in Figure 2 only

by the elimination of this sturctural gap between the cooling units 3_7 and 4. Therefore, the reference numbers of the individual structural parts and assemblies of Figure 3 are the same as the reference numbers of Figure 2. An exception to this is the first cooling unit 3_1', whose upper spray bar, in contrast to the spray bar of cooling unit 3_1 in Figure 2, is designed with the standard length of the cooling units 3_2 to 3_7.

In most cases, each cooling unit has four spray bars on both the upper side and the lower side. Each spray bar in turn consists of two rows of small water pipes for cooling the upper surface of the strip 10' and the lower surface of the strip 10". As a special feature, the cooling unit 3_1 in Figure 2 is shortened by one spray bar on the upper side due to limited space.

In contrast to the upstream cooling units 3_{1-7}, which have one switchable valve 7 per spray bar, the trimming zone 4 has two valves 7 for each spray bar. This means that in the trimming zone, each row of small cooling pipes can be individually controlled, and thus the amount of water can be more finely controlled.

The delivery speed of the strip from the finishing train varies with the rolled thickness of the finished strip.

Accordingly, the mode of operation of the cooling line must be adjusted to be able to adjust the time-temperature control necessary for the adjustment of the strip properties. For a strip thickness of 3 mm, for example, the first required cooling level is attained with the cooling units 3_1 and 3_2, while the second cooling level is realized with cooling units 3_5, 3_6, 3_7, and 4. Due to the altered boundary conditions for a finished strip with a thickness of 2.0 mm, only cooling units 3_6, 3_7, and 4 need to be used for the second cooling stage.

<u>List of Reference Numbers</u>

1	cooling line
2	last finishing stand
3_{1-7}	water cooling units
4	water cooling unit (trimming zone)
5	coiler
6	temperature-measuring point
7	switchable valve
8	direction of conveyance
10	hot-rolled strip
10'	upper surface of the strip
10"	lower surface of the strip
V_1	cooling rate of the first cooling stage
V_2	cooling rate of the second cooling stage
T_{finish}	strip temperature after the last finishing stand
$T_{const.}$	strip temperature after the holding time
$T_{coiling}$	strip temperature at the end of cooling (coil temperature)